SWINOMISH LARVAL AND JUVENILE DUNGENESS CRAB MONITORING REPORT FOR 2021

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ABSTRACT

The Dungeness crab (*Metacarcinus magister*) is one of the most highly-valued marine species in the Pacific Northwest. Throughout the region, the species forms the basis for many local fishing economies and is prized for its cultural and recreational significance. Although the biology and ecology of *M. magister* is relatively well-understood compared to other marine invertebrates, fundamental gaps still exist, notably in crab populations within the inland waters of the Salish Sea. In 2018, Swinomish began monitoring the larval flux, juvenile settlement and growth, and ecology of Dungeness crab at sites in northern Whidbey and southern San Juan Basins. Over the course of the 2021 monitoring season, larval Dungeness crab were observed at all three larval flux sites from May to August, with peak larval delivery observed between mid-June and early-July. At our beach sites, peak intertidal densities lagged behind the larval peaks, with peak settlement (stage 1 instars, J1) and overall densities observed in mid-July. Over this protracted Dungeness crab larval delivery period, postlarval and early instar Dungeness crab sizes were found to vary by month, with early arriving megalopae and J1 instars having significantly larger carapace dimensions than later arriving cohorts. This pattern of decreasing larval sizes by month has been consistent across monitoring years. Through our intertidal surveys, we found that Dungeness crab that settled in June reached up to 20 mm by October, whereas those that settled in late-July/August were ~10 mm. The annual larval flux totals at Cornet Bay (n = 100,480) and Anacortes (n = 39,336) were notably higher, whereas Rosario (n = 16,766) was similar compared to previous years. Relative to other crab species observed, Dungeness crab had the longest larval period with near constant presence from May to August, however, *Cancrid* spp. (*Cancer productus* and *Glebocarcinus oregonensis*) were captured in the highest abundances. Continuing to develop a baseline understanding of larval and juvenile dynamics across San Juan and Whidbey Basins could have far-reaching implications for continued successful management of this essential fishery and provide valuable data to inform future management practices as environmental conditions change.

Keywords Dungeness crab, *Metacarcinus magister*, larvae, larval flux, recruitment, juvenile, Puget Sound

INTRODUCTION

This report summarizes the annual dynamics of early life-history phases of Dungeness crab [*Metacarcinus* (*Cancer*) *magister*] in northern Whidbey and southern San Juan Basins during 2021. Included in this report are data summaries from the larval flux and intertidal density and growth surveys conducted by the Swinomish Fisheries Department. These activities are the basis of a long-term monitoring effort developed with the aim of resolving extensive gaps in our knowledge of early life history phases of *M. magister* in northern Puget Sound and the southern Strait of Georgia. In addition, we aim to develop a baseline of biological and physical metrics in the region in order to determine potential limitations to adult populations and assess the need for more adaptable management plans.

METHODS

Dungeness crab larval flux surveys

Over the course of the 2021 monitoring season, light traps were deployed from April to September at three locations to monitor the relative abundance of larval Dungeness crab in San Juan and Whidbey Basins (Figure 1). The Cornet Bay (COR), Rosario Head (ROS), and Seafarers Memorial Park in Anacortes (ANA) sites were monitored in 2021 (Table 1), while the Naval Air Station Whidbey Base in Oak Harbor (OAK) site was discontinued due to logistical reasons (Grossman et al. 2022). The COR, ROS, and ANA traps were deployed on 29 March 2021. Light traps were pulled from the water, ending the monitoring period after roughly two weeks (one full tidal cycle) of zero catch, on 8 September 2021 for ROS and ANA, and 13 September 2021 for COR.

Larval crab catch (inclusive of megalopae and juvenile stage one "J1" instars that molted in the trap between site visits) was standardized by catch per hour (megalopae/hr). In addition, carapace dimensions including carapace width (CW), carapace height (CH), and total height (TH), of 30 megalopae and instars (if present from megalopae that molted in the trap) were measured per week, per site. A more detailed explanation of methods can be found in Cook et al. (2018).

Table 1. Location metadata of larval flux sites in 2021.

Site Code	Location	Basin	Shellfish Management Area	Subregion
ROS	Rosario Head, Oak Harbor, WA	San Juan	1	22A
ANA	Seafarers Memorial Park, Anacortes, WA	San Juan	1	22B
COR	Cornet Bay, Oak Harbor, WA	Whidbey	2E	24A

Juvenile Dungeness crab intertidal surveys

Intertidal areas of two beaches were monitored: Cabana Park near Skyline Marina (SKY) in San Juan Basin and Cornet Bay (COR) in Whidbey Basin (Table 2, Figure 1). Intertidal surveys were conducted once a month from January to December in 2021 during low tides at Skyline (SKY). Because the intertidal densities were low in fall 2020 at COR, we did not start monitoring there until March 2021. In previous years, we sampled intertidal locations bi-weekly during the settlement season, and periodically over winter months. As our understanding of patterns between larval supply and settlement at our survey locations improved, we switched to a more regular monthly schedule to both capture settlement metrics during the larval delivery season and growth and survival metrics while the young-of-the-year (YOY) crab occupy the intertidal habitats. As with previous years, surveys were conducted using a randomized sampling scheme with 10 0.25 m^2 quadrat samples per beach monitoring event. At each sample site, quadrats were excavated to a depth of 3 cm and all materials were collected in a 4 mm sieve and rinsed with local seawater to remove material < 4 mm from

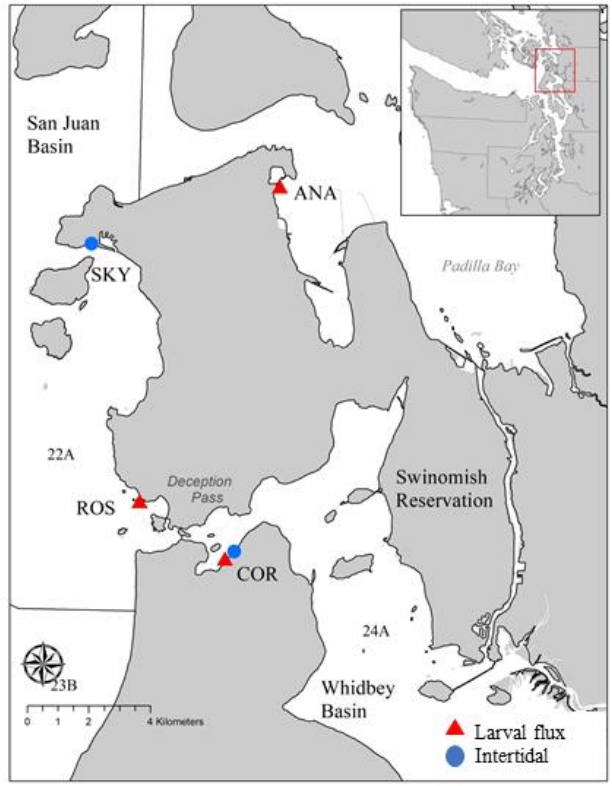

Figure 1. Location of larval flux and intertidal monitoring sites in San Juan and Whidbey Basins. Numbers depict management subregions.

Table 2. Location metadata for intertidal sampling beaches.

Site Code	Location	Basin	Shellfish Management Area	Subregion
SKY	Cabana Park, Anacortes, WA	San Juan	1	22A
COR	Cornet Bay, Oak Harbor, WA	Whidbey	2E	24A

the bulk sample. The remaining materials were sorted through and all Dungeness crab instars and megalopae were enumerated and CW and CH were recorded. Detailed methods on how to conduct our intertidal surveys can be found in Grossman et al. (2021).

Ecological context

In addition to monitoring for Dungeness crab larval and juvenile abundance we quantified sample bycatch in both our light trap and intertidal excavated quadrat samples. All decapod species captured were identified to the lowest taxonomic group possible and enumerated. A summary of the total catches over time is presented for crab species found during larval flux monitoring.

Surface water temperature was monitored at COR, ROS, and ANA larval flux sites from 29 March to 13 September 2021, using HOBO U24-002-C loggers programmed to collect readings at 15-minute intervals. Daily mean temperature °C was calculated and plotted by site.

Analysis

Summary statistics were used to characterize Dungeness crab larval abundance at sites through time. The 2021 larval crab monitoring season was broken up into three time periods: early-season (ES) 31 March to 14 June, mid-season (MS) 15 June to 25 July, and late-season (LS) 26 July to 13 September.

Carapace widths of Dungeness crab megalopae collected in larval flux sites were compared both between sites and by month. Using a non-parametric Kruskal-Wallis (KW) test, we first tested if mean CW, regardless of month, differed among sites and used a follow-up Conover-Inman test (Bonferroni p-adjusted with alpha set to 0.05) to determine where differences existed. Because there were differences in megalopae CW between some sites, we followed up with individual KW tests on megalopae CW by month for each site independently. Subsequent temporal analyses were performed using the post-hoc Conover-Inman test (Bonferroni p-adjusted with alpha set to 0.05) (Sokal & Rohlf 2012).

Intertidal densities were qualitatively assessed and described with summary statistics. To examine the relationship between Dungeness crab settlement [defined here as megalopae and/or juvenile stage 1 (J1) instars] and recruitment (J2+ instars), and their relative contributions to total crab intertidal density, the densities of settlers and recruits were plotted by sampling date.

RESULTS AND DISCUSSION

2021 Dungeness crab larval catch

Dungeness crab megalopae were first observed on 18 May at ROS, 20 May at COR, and 30 May at ANA (Figure 2). The 2021 arrival dates were the latest of the 2018 to 2021 record. Despite the late arrival, 2021 total annual catches were much higher than previous years at COR and ANA and were similar at ROS.

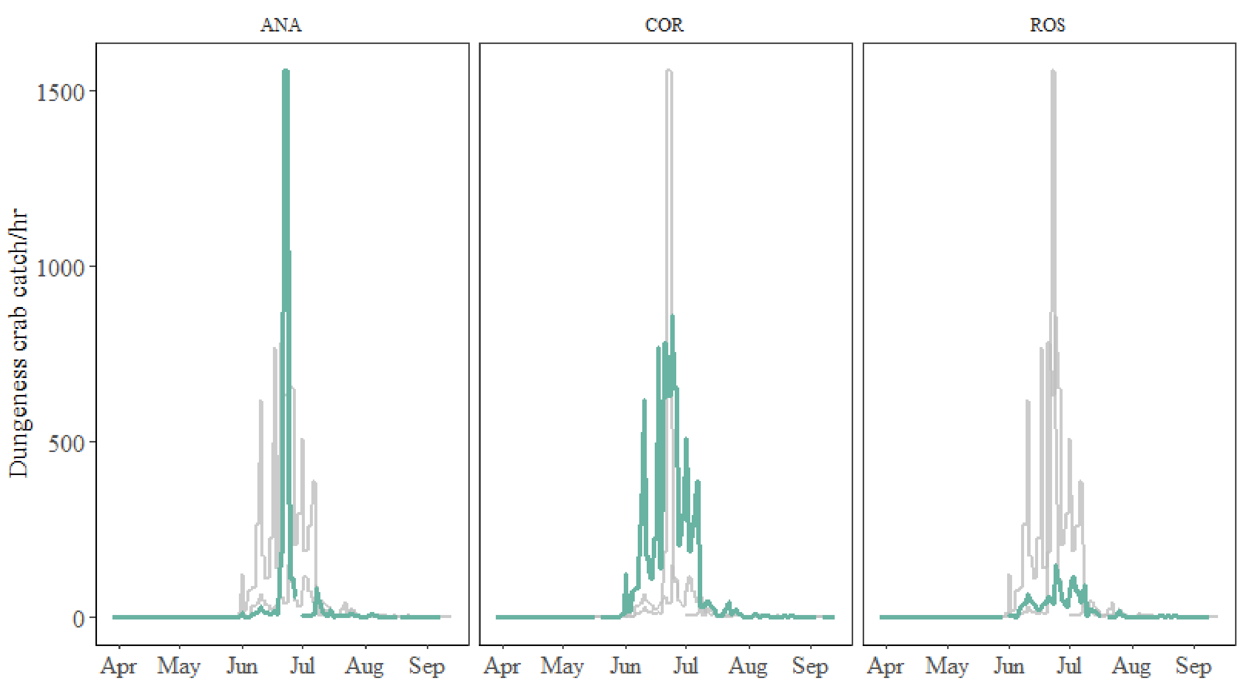

Figure 2. Dungeness crab catch per hour at Anacortes (ANA), Cornet Bay (COR), and Rosario (ROS) from April to September 2021. Gray lines represent the catch from all three sites overlaid with green lines representing the catch from the individual site.

Table 3. Dungeness crab CPUE (catch/hr), minimum, maximum, mean, standard error (se), sum of *M. magister* larvae captured, and days sampled by period. Statistics tallied by early-season (31 March to 14 June), mid-season (15 June to 25 July), late-season (26 July to 13 September), and total season from 31 March to 13 September 2021.

	31 Mar to 14 Jun	ANA	COR	ROS
Early-season	min CPUE	0.0	0.0	0.0
	max CPUE	31.1	619.0	63.4
	mean CPUE ± se	1.87 ± 0.6	29 ± 10.1	4.92 ± 1.6
	Total catch	1,168	17,639	3,064
	Days sampled	78	78	78
	15 Jun to 25 Jul	ANA	COR	ROS
Mid-season	min CPUE	0.5	2.5	0.2
	max CPUE	1558.0	861.0	147.0
	mean CPUE ± se	120 ± 56.3	245 ± 42.1	40.8 ± 6.0
	Total catch	37,589	81,912	13,166
	Days sampled	41	41	41
	26 Jul to 13 Sep	ANA	COR	ROS
Late-season	min CPUE	0.0	0.0	0.0
	max CPUE	6.9	19.4	16.1
	mean CPUE ± se	1.2 ± 0.3	1.7 ± 0.5	1.0 ± 0.4
	Total catch	579	929	536
	Days sampled	45	50	45
	31 Mar to 13 Sep	ANA	COR	ROS
2021 Total	min CPUE	0.0	0.0	0.0
	max CPUE	1558.0	861.0	147.0
	mean CPUE ± se	30.4 ± 14.1	74.8 ± 13.7	12.6 ± 2.1
	Total catch	39,336	100,480	16,766
	Days sampled	164	169	164

The total seasonal abundance of Dungeness crab megalopae was the highest at COR, with 100,480 megalopae captured in 2021. Total abundances at ANA were higher than ROS in 2021 (despite no larval catch at ANA in May), with 39,336 and 16,766 megalopae captured, respectively. The highest daily catch across all sites was recorded at ANA (1,558.0 catch/hr) in mid-June 2021 (Figure 2, Table 3). Most of the larval catch from ANA was captured during the period between 20 to 28 June. At COR larval catches were relatively high for a longer time period, from 1 June to 22 July, with maximum catches occurring on 24 June (860.8 catch/hr). In comparison, the catches at ROS were low throughout the delivery season, with a maximum daily catch of 147.0 catch/hr on 24 June. Across all sites, catches diminished greatly from the mid-season peaks by August (< 10 catch/hour; Figure 2). The last Dungeness crab megalopae were caught on 24 August at ANA, 30 August at COR, and 1 September at ROS.

The highest larval abundances were observed in the mid-season at all three sites. While the larvae arrived later in 2021 relative to previous years, the early season catch accounted for between 18 % (at COR and ROS) and 3 % (ANA) of the total season catch. In the mid-season, catch rates increased at all three sites with seasonal abundances representing 96 % at ANA, 79 % at ROS, and 82 % of the total catch at COR. In the late-season, 1 % of the total annual catch was caught at ANA and COR, and ROS had 3 % of total catch.

Dungeness crab megalopae carapace width

Consistent with previous years, over the course of the 2021 monitoring season, the carapace widths of megalopae delivered varied spatially and decreased over time. From May to August 2021, a significant difference was observed between CW by site ($X^2 = 7.39$, df = 2, p = 0.02, Table 4). Follow-up tests revealed that throughout the entire delivery period, CW's were significantly smaller at ANA (2.4 ± 0.01 SE mm) compared to COR (2.5 ± 0.02 SE mm) but not significantly different from ROS (2.5 ± 0.02 SE mm). No difference was detected between megalopa CWs from COR and ROS (Tables 4 & 5).

The CWs of megalopae showed a steady and significant decline by month at sites until the end of the larval delivery period, with the exception of COR between May and June and ROS from July and August (Figure 3 & Table 6). The mean CW of megalopae at COR increased slightly from May (2.5 ± 0.04 SE mm) to June (2.6 ± 0.03 SE mm). Interestingly, at nearby ROS the mean CW was 0.3 mm

Table 4. Kruskal-Wallis (X^2) and Conover-Iman (t-statistic) follow-up test results of carapace width by site [Anacortes (ANA), Cornet Bay (COR), Rosario (ROS)].

Kruskal-Wallis $X^2 = 7.39$, df = 2, p-value = 0.02				
	ANA		COR	
	t	p	t	p
COR	-2.63	0.013*		
ROS	-2.86	0.07	0.54	0.88

Bonferroni p-adjusted alpha = 0.05

Table 5. Count (n), mean, and standard error (se) of megalopae carapace width by month at Anacortes (ANA), Cornet Bay (COR), and Rosario (ROS) sites in 2021.

	ANA		COR		ROS	
	n	mean ± se	n	mean ± se	n	mean ± se
May	0	-	53	2.5 ± 0.04	24	2.8 ± 0.08
Jun	113	2.5 ± 0.02	133	2.6 ± 0.03	127	2.5 ± 0.03
Jul	103	2.4 ± 0.02	94	2.4 ± 0.02	94	2.4 ± 0.03
Aug	55	2.2 ± 0.01	57	2.3 ± 0.02	33	2.3 ± 0.03
All 2021	271	2.4 ± 0.01	337	2.5 ± 0.02	278	2.5 ± 0.02

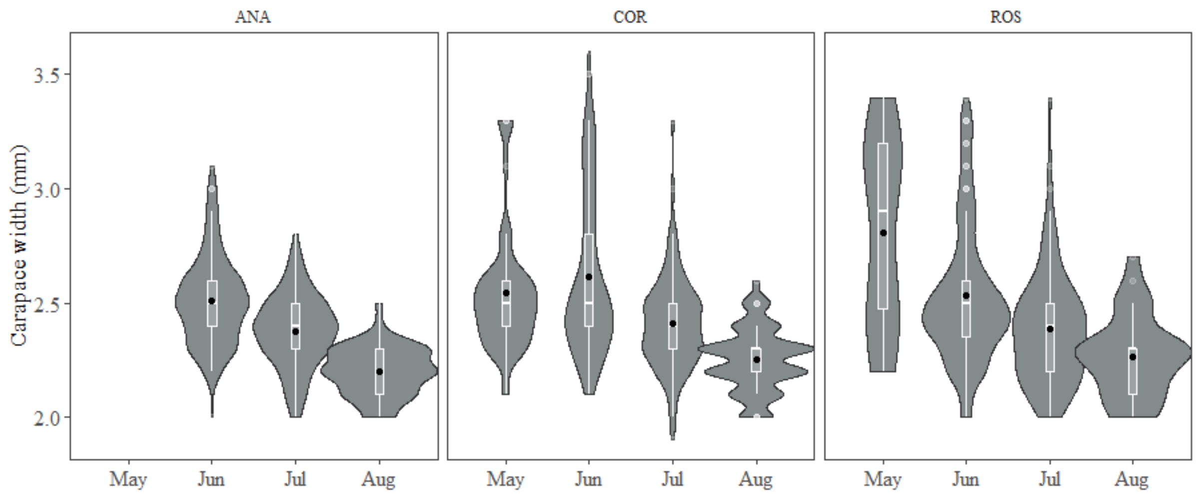

Figure 3. Violin plots depicting the relative distribution, proportion, and mean (dot) of carapace width (mm) of Dungeness crab megalopae caught in light traps [Anacortes (ANA), Cornet Bay (COR), and Rosario Head (ROS)] from May to August 2021.

larger than COR in May. Given the location of ROS (nearest the eastern Strait of Juan de Fuca) the proportion of larvae from 'larger' outer coast populations relative to 'smaller' local populations could have been higher in May relative to COR. There were very few megalopae captured in May 2021 (relative to other months; none were captured at ANA) and of the measurements collected, most were under 3.0 mm (Figure 3). In comparison to previous years, CW results indicate that very few of the hypothesized outer coast larvae were delivered to the eastern Strait of Juan de Fuca in the early delivery period of 2021. The megalopae delivered to all three sites throughout the May to August larval period were primarily comprised of the smaller size classes of megalopae, arriving during the mid-season.

Table 6. Kruskal-Wallis (X^2) and Conover-Iman (t-statistic) follow-up test results of megalopae carapace width by month, across sites [Anacortes (ANA), Cornet Bay (COR), Rosario (ROS)].

	ANA		COR		ROS	
X^2	95.32		75.37		45.71	
p	<0.000*		<0.000*		<0.000*	
	t	p	t	p	t	p
May vs. Jun	-	-	-0.29	1	2.77	< 0.001*
May vs. Jul	-	-	3.24	0.004*	5.03	< 0.001*
May vs. Aug	-	-	7.44	< 0.001*	6.17	< 0.001*
Jun vs. Jul	5.52	< 0.001*	4.48	< 0.001*	3.92	0.000*
Jun vs. Aug	12.07	< 0.001*	9.26	< 0.001*	5.33	< 0.001*
Jul vs Aug	7.38	< 0.001*	5.14	< 0.001*	2.51	0.03

Juvenile Dungeness crab intertidal surveys

Dungeness crab juvenile settlement density

In 2021 we monitored intertidal sites monthly during the pre-settlement season (starting in 31 March at COR), the settlement period (i.e., while megalopae were observed in larval traps), and the post-settlement season. This monitoring schedule allowed us to observe the densities and sizes of Dungeness crab that overwintered in the intertidal habitats prior to the arrival of the next year class, in addition to tracking the current year's cohorts.

Across the 2021 intertidal monitoring period, Dungeness crab densities were not significantly different between sites (X^2 = 1.523, df = 1, p = 0.217), but significant differences were detected across months (X^2 = 78.84, df = 10, p < 0.001). During the pre-settlement season 31 March survey, one crab was caught across all quadrats sampled at COR resulting in a mean density of 0.4 crab/m^2. At SKY the maximum pre-settlement season intertidal density from the March survey was 2.7 crab/m^2. By the end of May, no J1 instars were found at the beach sites, despite low levels of megalopae caught in the light traps, and intertidal Dungeness crab densities were 0.0 crab/m^2 at SKY and 0.4 crab/m^2 at COR. The one crab caught at COR in May had a CW of 54.3 mm and was likely from the 2020 cohort. The low densities of recruits (J2+ instars) in May suggests that the juvenile instars found over the winter months (settlers from the previous year) migrated to subtidal habitats by early spring, ahead of the next wave of larval settlement (also observed in McMillan et al. 1995).

Peak intertidal densities at both sites (36.0 ± 16.3 SE m^{-2} at COR and 29.2 ± 6.6 SE m^{-2} at SKY) were observed in mid-July 2021, with the composition primarily made up of recent settlers (J1 instars; Figures 4 & 5). By late August, intertidal Dungeness crab densities were still near the seasonal peak (mean density 9.6 ± 3.5 SE m^{-2} at COR and 21.6 ± 6.4 SE m^{-2} at SKY) though the composition of crab caught differed and were mostly made up of J2+ instars (Figures 4 & 5). By October, intertidal densities at COR

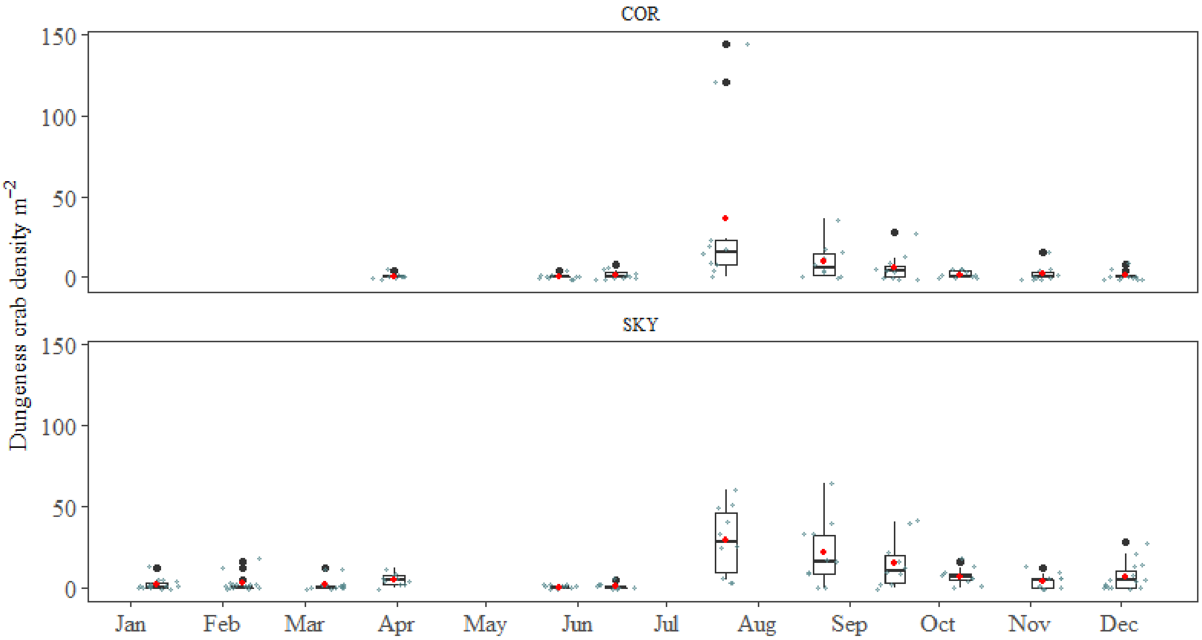

Figure 4. Median, mean density (red dot) and distribution (grey jitter) of intertidal Dungeness crab m^{-2} at Cornet Bay (COR) and Skyline (SKY) in 2021.

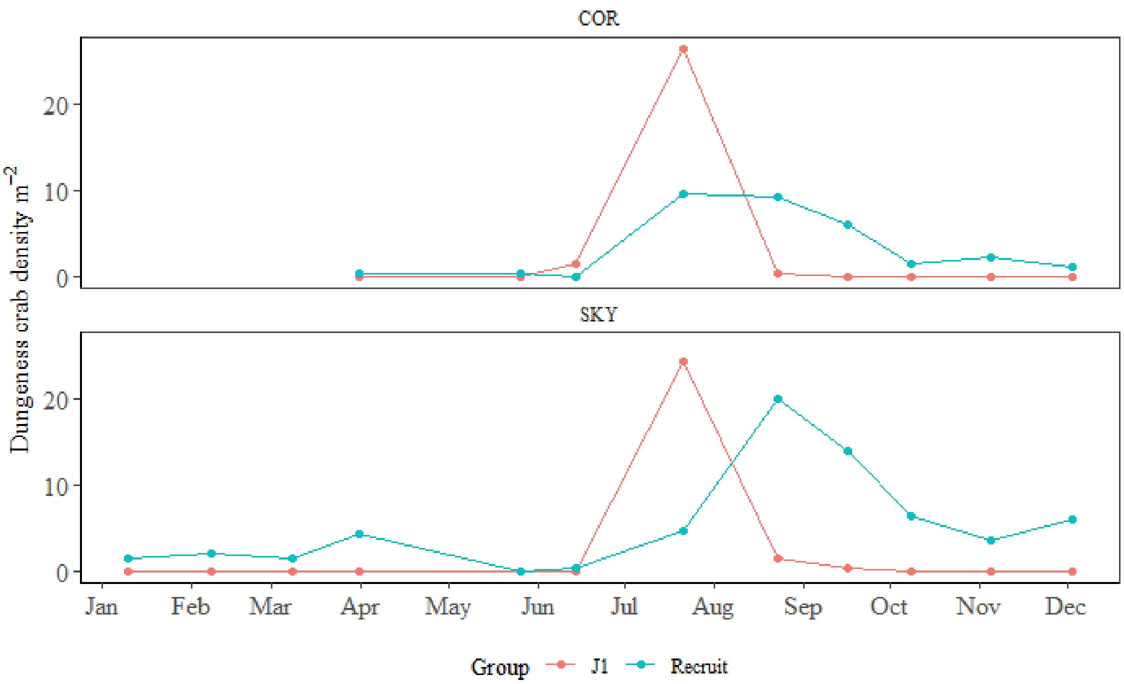

Figure 5. Mean density of intertidal Dungeness crab juvenile stage 1 (J1) instars (red, recent settlers) and recruits (blue, J2 and larger instars) at Cornet Bay (COR) and Skyline (SKY) from January to December 2021.

and SKY leveled off and ranged between 1.1 ± 0.8 SE m^{-2} and 6.4 ± 1.6 SE m^{-2}, over the fall/winter months (Figure 4).

Dungeness crab size and instar stage composition

In addition to tracking larval flux and intertidal densities over time, we were interested in tracking growth and development of 0+ juvenile crab (up to ~25 to 40 mm CW;

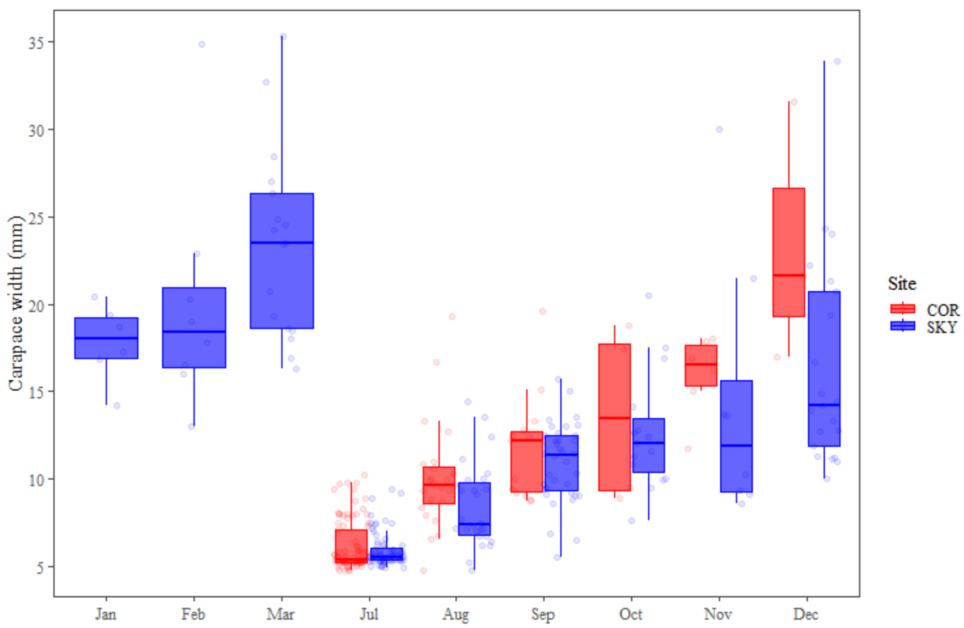

Figure 6. Distribution of carapace widths (mm) by month of intertidal Dungeness crab instars caught from San Juan Basin (orange) and Whidbey Basin (blue) in 2021. Note that no crab < 40 mm were recorded in May and only megalopae were noted in June.

Armstrong et al. 1989, Gunderson et al. 1990) while they occupy intertidal nursery habitats. As with the megalopae captured in the light traps (see discussion above), the CW of J1 instars found during surveys gradually decreased from June to August at our intertidal sites.

In January and February, intertidal Dungeness crab found on the beach are mostly likely from the 2020 settlement season with carapace widths ranging from 13.0 to 34.9 mm (Grossman et al. 2022). Beginning in March, we believe that the spring water temperatures warmed enough to reinitiate growth, as the mean CW increased to 23.4 ± 1.32 SE mm from 20.1 ± 2.37 SE mm in February (Figure 6). From April to May, these larger crabs likely migrated to the subtidal since no Dungeness crab less than 40 mm CW were found during the May survey, and only megalopae were found on the beach in June. Appreciable settlement from the 2021 cohort was observed at both sites in July 2021, when most of the crab found on the beaches were made up of J1 instars. However, the size ranges (4.8 to 10.2 mm at COR; 4.9 to 9.4 mm at SKY) reflect the presence of instars that have molted up to two times (maximum J3 instar stage; Dinnel et al. 1993). As the summer progressed, mean carapace widths increased to 11.8 ± 0.81 SE at COR and 10.9 ± 0.38 SE at SKY in September. While the larval delivery period was largely over by September, J1 instars were still present in low numbers at SKY (minimum CW 5.5 mm). The largest instars found in September were 15.7 mm at SKY and 19.6 mm at COR. The instars from the 2021 settlement season found in December exhibited a considerable range of sizes (17.0 to 31.6 mm at COR; 10.0 to 33.9 mm SKY). The largest of these crab likely settled in late-June, while the smallest likely settled in late-August/early September. Interestingly, by the end of the year the smallest of the instars were absent from COR, despite larval delivery into August 2021. It is unclear if conditions at the site expedited growth, relative to SKY, or if there was poor survival of the later settling small instars.

Interannual variability of Dungeness crab larval abundance and sizes

From 2018 to 2021, larval Dungeness crab catches from across our monitoring sites varied greatly between site and years (Table 7). Total annual catch abundances at COR were similar in 2018 and 2019 (n = 20,592 and 19,744, respectively) but total catch was roughly 57% lower in 2020 (n = 8,427) before reaching the highest levels yet with 100,480 captured in 2021. Larval catches at ROS were lowest in 2018 (with 3,176 megalopae captured) and catches increased 446% in 2019 and catches were relatively level from 2019 to 2021 (Table 7). Interestingly,

Table 7. Total annual abundance of larval Dungeness crab caught in light traps by site and year.

	ANA	COR	ROS
2018	-	20,592	3,716
2019	5,124	19,744	16,589
2020	729	8,427	20,110
2021	39,336	100,480	16,766

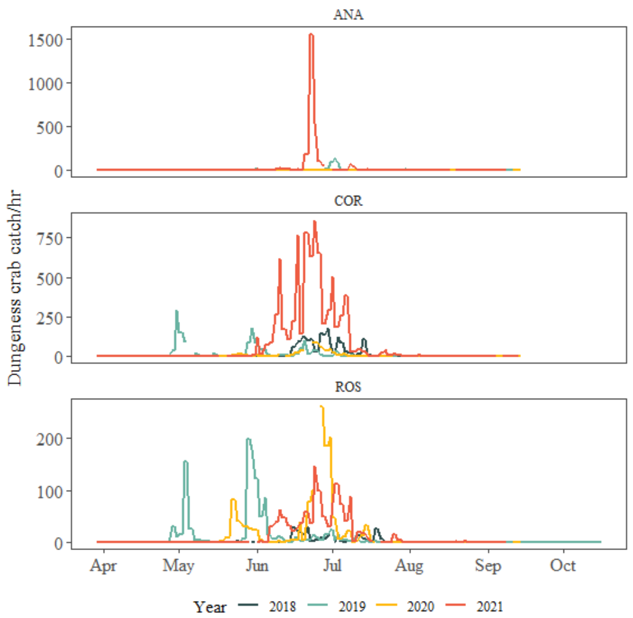

Figure 7. Dungeness crab catch per hour at Anacortes (ANA), Cornet Bay (COR) and Rosario (ROS) from April to October. Green lines represent the catch from 2018, black lines 2019, yellow 2020, and red 2021.

total annual larval catches at ANA, which was not monitored in 2018, exhibited patterns similar to COR, though at a lower magnitude. This observation is compelling because ANA and COR are located relatively far away from each other in unconnected water bodies, whereas ROS and COR are within 3.5 km proximity to each other, on either side of Deception Pass. It is possible that regional scale weather conditions from winter to spring, likely affect northern Whidbey and southern San Juan basins evenly. Thus, year to year differences in conditions set up water conditions that are more or less conducive to survival of annual larval cohorts at ANA and COR similarly. Yet, other factors such as surface water circulation and/or residence times near the ROS site, relative to ANA and COR, may be more strongly influencing catches at that location.

The timing of larval pulses also varied across years, with each year between 2018 and 2021 exhibiting unique delivery patterns (Figure 7). The timing of larval delivery in 2018 and 2021 were relatively similar, where catches at COR and ROS were relatively low (< 100 megalopae/day) until mid-June when much larger catches were observed until tapering off again in mid-July. However, daily abundances were much higher during the mid-season 2021 pulses at COR in particular. In 2019, the majority of the larvae were delivered prior to mid-June at COR (79 % of total) and ROS (88 % of total), whereas at ANA the most significant pulse occurred in late June (Figure 7). Larval delivery patterns observed in 2020 were a mix of the previous two year's patterns. The early-season represented 17 to 23 % of the total catches at COR and ROS, followed by larger pulses in the mid-season at COR (82 % of total) and ROS (77 % of total). Across all monitoring years, the late-season catches were < 1 % of the total catch. It will take more years of monitoring before we can determine correlations between site specific circulation or oceanographic conditions and patterns of annual and within season larval delivery. Although, results from 2018 to 2021 appear to show that localized conditions may more similarly influence the patterns of delivery (although not magnitude) between ANA and COR, than at ROS, resulting in the prominent mid-season larval delivery.

In previous reports we have hypothesized that the larval pulses delivered to our study sites in April and May likely originate from Dungeness crab populations from the outer Pacific coast. Carapace dimensions of megalopae from outer coast populations have been shown to be larger than conspecifics from the inland waters of the Salish Sea (DeBrosse et al. 1990). Thus, our hypothesis continues to be supported by the consistent phenotypic differences observed (size and timing of larval delivery) between the start and end of the larval delivery season. In addition to differences in overall sizes of the megalopae, Dungeness crab from outer coast populations are present as post-larvae in the water column and have been shown to settle earlier in the spring and summer compared to populations from the Salish Sea (MacKay & Weymouth 1935, Gunderson et al. 1990, Jamieson & Phillips 1993, Sulkin et al. 1996). As noted above (see *Dungeness crab size and instar stage composition*), overall size and timing of delivery to the juvenile nursery habitats are important factors that could drive differences in growth rates and the relative time it takes for each cohort to reach important developmental milestones (Orensanz & Gallucci 1988).

Dungeness crab megalopae captured across all monitoring years were significantly larger at the start of the delivery season and the CW decreased progressively over the summer months (Figure 8). Taking a qualitative look at mean CWs by week from 2019 to 2021 a stark decrease in CWs is observed starting between late-May (2021) and early-June (2019). Though it is early to speculate, we believe that these abrupt decreases in mean CW (amongst the gradual seasonal decrease) represent shifts in the delivery of distinct cohorts.

It is likely too early in our research to speculate on the physical and/or biological factors influencing carapace dimensions, given that we are currently unable to determine the origins of larvae delivered to our monitoring sites. Within the central Salish Sea, larvae have the potential to be sourced from any of three genetically-differentiated adult populations (Jackson & O'Malley 2017). At this point in our research, we are unsure if the

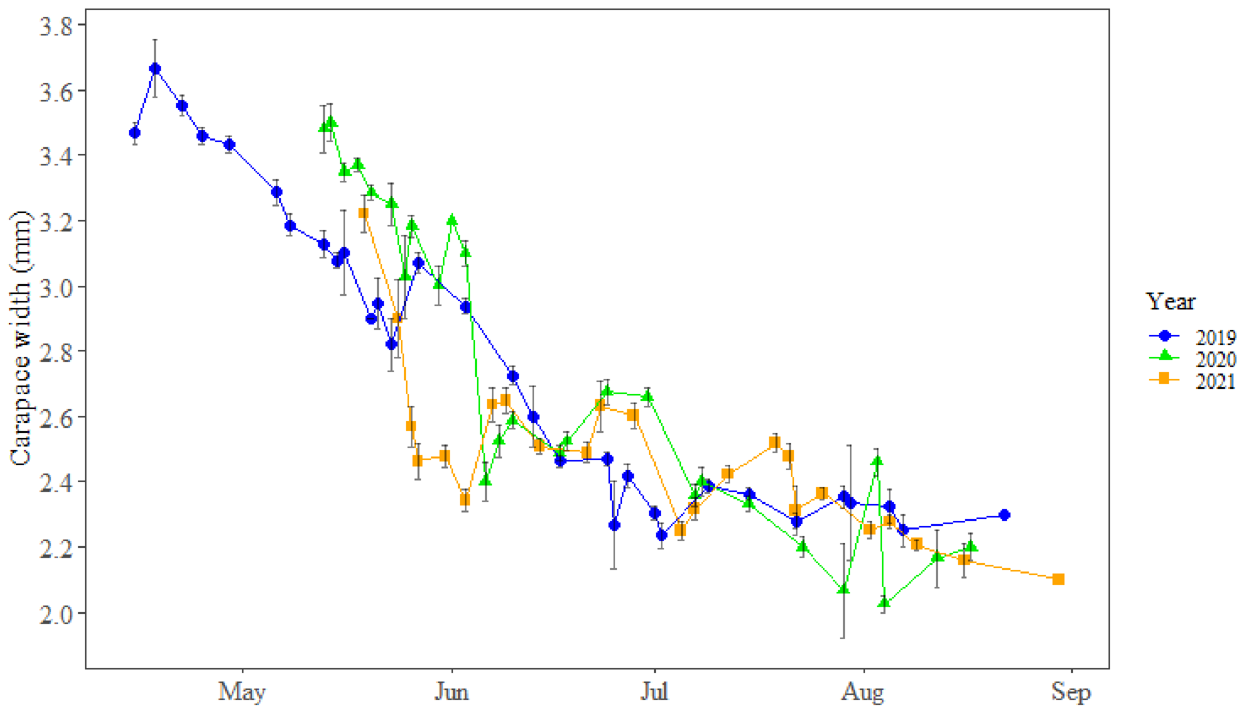

Figure 8. Mean carapace width +/- SE (mm) of Dungeness crab megalopae caught in light traps by year for 2019, 2020, and 2021. Data are pooled from sites Anacortes (ANA), Cornet Bay (COR) and Rosario (ROS).

M. magister larvae delivered to our sites in the early-season are larger than the late-season larvae because of a genetic predisposition or because they were reared in waters more conducive to greater or lesser larval growth, or some combination of these two hypotheses. We hope to investigate these hypotheses further through additional years of monitoring larval dynamics and ocean conditions at our research sites and by analyzing regional and temporal genetic variability paired with circulation modeling.

Ecological context

Other species - larval flux

While Dungeness crab were the focus of this study, we also observed 14 other larval crab species/species groups, including the following most abundant species: *Cancrid* spp. (*Cancer productus* and *Glebocarcinus oregonensis,* combined because of the logistical limitations of differentiating the magnitudes of these species on a daily basis*)*, *Lophopanopeus bellus*, *Hemigrapsus* spp. (*H. oregonensis* and *H. nudus*), *Oregonia gracilis*, and *Pugettia* spp (Table 8; *Pagurus* spp. were also found at all sites, though only daily presence was recorded). Other less abundant species include: *Acantholithodes hispidus*, *Cryptolithodes typicus*, *Fabia subquadrate*, *Metacarcinus gracilis*, *Placetron wosnessenskii*, and *Telmessus cheiragonus* (Table 8).

Dungeness crab larvae were present in varying abundances from May to September, however each of the other species captured in the light traps exhibited more discrete delivery periods. The first species present in the larval traps were *C. typicus*, *L. bellus*, *P. gracilis*, and *F. subquadrata*, observed during April 2021. The most abundant of those species, *L. bellus*, was present across our sites from 1 April

Table 8. Abundances of crab families, genus, or species observed at Anacortes (ANA), Cornet Bay (COR), and Rosario (ROS) larval crab monitoring sites in 2021.

	ANA	COR	ROS
Acantholithodes hispidus	4	-	5
Cancrid spp.	11,411	354,609	6,894
Cryptolithodes typicus	1	-	8
Fabia subquadrata	7	14	28
Hemigrapsus spp.	397	2,328	642
Lophopanopeus bellus	1,504	4,286	7,606
Metacarcinus gracilis	1	49	8
Metacarcinus magister	39,336	100,481	16,766
Oregonia gracilis	28	826	817
Pachycheles pubesens	-	-	3
Pinnixa spp.	264	152	38
Placetron wosnessenskii	1	1	-
Pugettia gracilis	44	6	8
Pugettia sp.	17	117	15
Telmessus cheiragonus	2	-	-

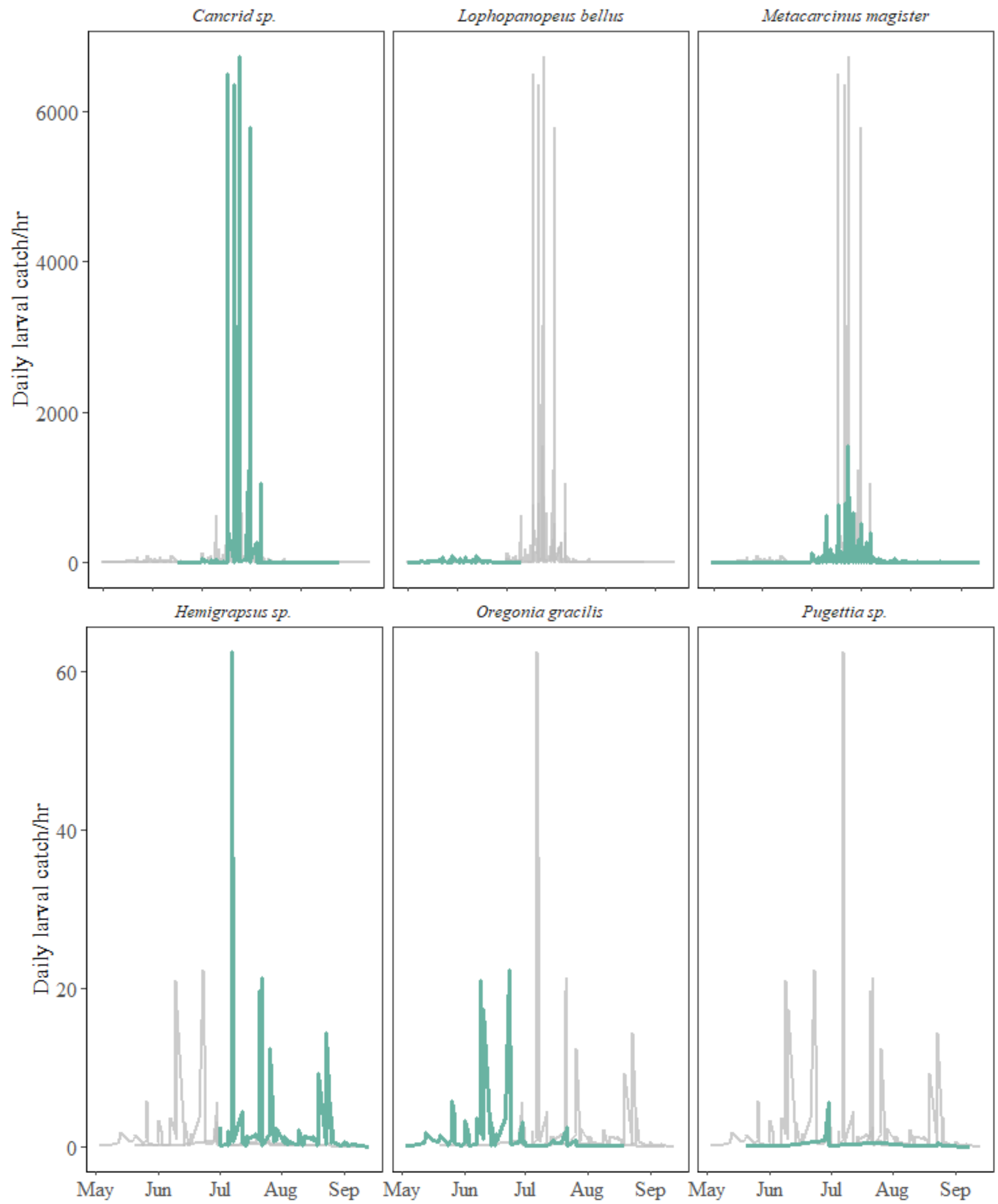

Figure 9. Daily larval crab catches (all sites combined) of *Cancrid* spp. (*Cancer productus* and *Glebocarcinus oregonensis*), *Hemigrapsus* spp., *Lophopanopeus bellus*, *Metacarcinus magister*, *Oregonia gracilis*, and *Pugettia* spp. (April to October 2021). Gray lines represent the daily catch of all listed species and the overlaid green line represents the catch of the target species.

to 10 June 2021 and the most abundant at ROS (Table 8, Figure 9).

Starting in May, we began to observe *A. hispidus*, *O. gracilis*, *P. wosnessenskii*, *Cancrid* spp., *Pinnixa* spp., and *P. producta* in the larval traps. Of these species, the *Cancrid* spp. group were the most abundant, particularly at COR where we caught 354,609 megalopae across the season (Table 8, Figure 9). In June, we observed *P. pubesens* at ROS and *M. gracilis* at COR and ROS for the first time in 2021. The last two species to arrive were *Hemigrapsus* spp. (July) and *T. cheiragonus* (August).

Environmental conditions
Monthly mean surface water temperatures were generally coolest in April and warmest in August and ranged from 9.37 (COR in April) to 15.62 ºC (ANA in August). Seasonal temperature ranges were smallest at ROS (8.25

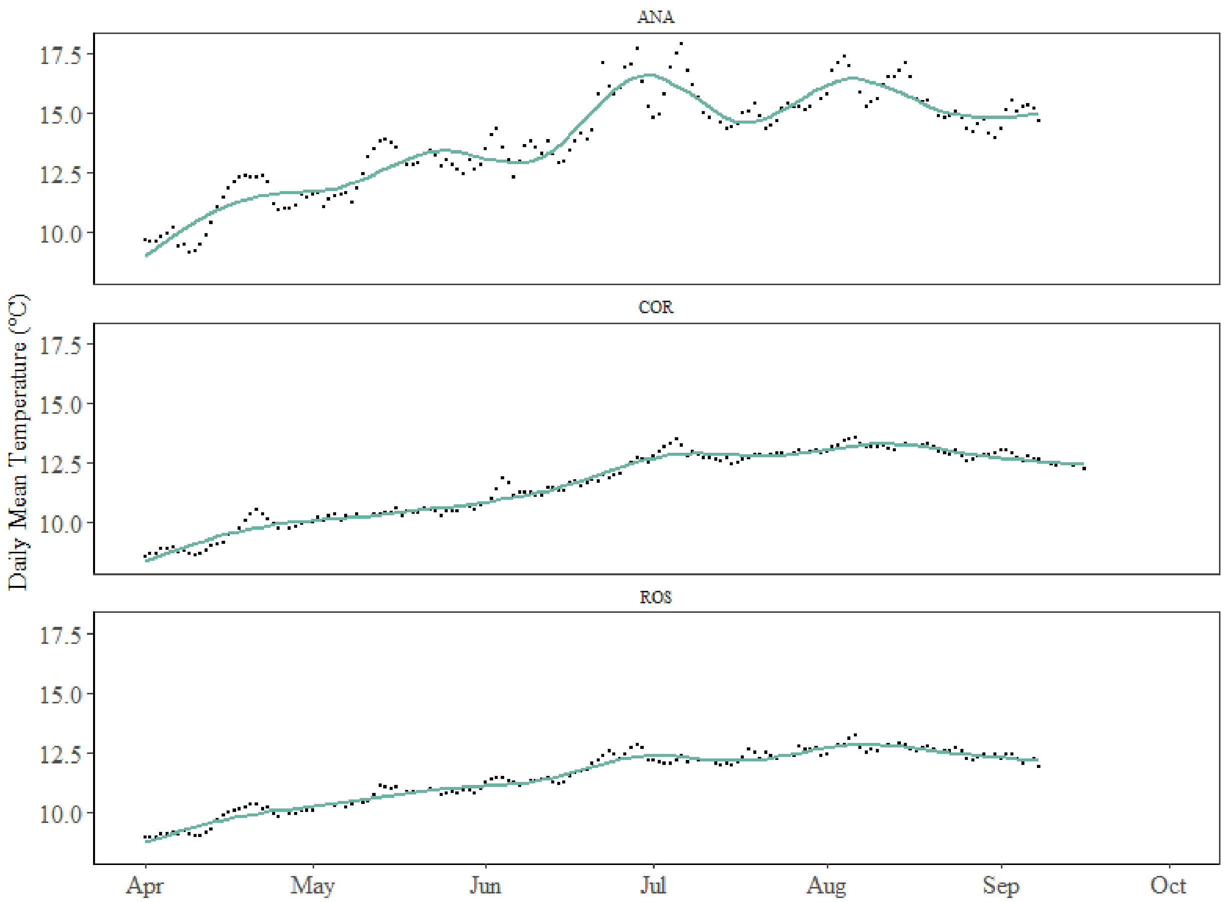

Figure 10. Mean daily surface water temperature [degrees Celsius (°C)]) with a smooth function trend line from April to September 2021 at Anacortes (ANA), Cornet Bay (COR), and Rosario (ROS).

to 15.1 ºC) and largest at ANA (8.54 to 20.3 ºC). The seasonal range at COR (8.09 to 17.2 ºC) was more moderate, relative to ANA and ROS (Figure 10).

At ANA, the lowest April to September temperatures were recorded in April (minimum = 8.5 ºC; monthly mean 10.8 ºC ± 0.02 SE) while the highest temperature reading was recorded in June (20.3 ºC) and the highest monthly mean in August (15.5 ºC ± 0.02 SE). Water temperatures at COR similarly were lowest in April (minimum = 8.1 ºC; monthly mean 9.4 ºC ± 0.01 SE) and highest in August (maximum 16.0 ºC; monthly mean 13.1 ºC ± 0.01 SE). At ROS, the minimum temperature recorded was 8.3 ºC (April monthly mean 9.6 ºC ± 0.01 SE) and a maximum temperature of 15.1 ºC was recorded in August (monthly mean 12.6 ºC ± 0.01 SE). On the date the first Dungeness megalopae were observed, the mean surface water temperatures were 10.8 ºC (10.3 to 11.8 ºC) at ROS (18 May), 10.4 ºC (9.8 to 11.8 ºC) at COR (20 May), and 12.7 ºC (11.3 to 14.3 ºC) at ANA (30 May). All three sites observed the largest larval delivery peaks of the season around 24 June. On this date, the mean surface water temperatures were 12.4 ºC (11.3 to 14.5 ºC) at ROS, 11.9 ºC (11.3 to 13.1 ºC) at COR, and 15.8 ºC (14.3 to 17.6 ºC) at ANA.

While the surface water temperatures were more moderate at COR and ROS relative to ANA, it is unlikely that temperature alone can explain the difference in megalopal timing or abundance between the sites. Differences observed in the variability of water temperature between COR or ROS and ANA are likely due to COR and ROS's proximity to Deception Pass and the Strait of Juan de Fuca. The shallow sill at Deception Pass produces increased water column mixing as water is funneled through the Pass with each tidal exchange (Moore et al. 2008). The influence of the Strait at these sites is observed as relatively cooler temperatures of the water coming into Puget Sound from the Pacific (Masson 2006). In contrast, ANA is located in a broad embayment where water residence time is likely higher and the surface waters are more influenced by ambient air temperatures and spring/neap tidal cycles. Over time we hope to incorporate additional water property parameters and depth profile measurements to gain a better understanding of site-specific characteristics and, eventually, evaluate how water properties influence presence, growth, and survival of Dungeness crab across Swinomish management regions.

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